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Droplet Dynamics and Initial Field Tests for Microencapsulated Pesticide Formulations Applied at Ultra Low Volume Using Rotary Atomisers for Control of Locusts and Grasshoppers

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Abstract: The physical properties and field efficacy of microencapsulated acridicides (ME) were investigated to determine their suitability for application at Ultra Low Volume (ULV) rates in Sahelian conditions. Microcapsules were not damaged during application using Micronair AU7000 rotary atomisers. Drop size was dependent upon microcapsule size, smaller microcapsules tending to form dense aggregates within large droplets. The aggregation effect was counteracted by larger microcapsule sizes and by dilution of the concentrated formulation. There was a tendency for microcapsules to land dry at increasing distances from the point of application and at high temperatures and low humidities. In the field in Mali (W. Africa) diluted ME formulations were found to be suitable for ULV application by Berthoud C8 hand-held sprayers, vehicle-mounted Micronair AU7000 pest control kits and helicopter-mounted Beecomist rotary atomisers. ME formulations of fenitrothion, chlorpyriphos and diazinon all suppressed grasshopper populations in annual grassland and were as effective as fenitrothion applied at the standard ULV rate. The spatially heterogeneous and shifting nature of the grasshopper populations prevented the relative efficacy or persistence of the different products to be quantified and the potential for reduced environmental impact could not be tested.

Key words: microencapsulated insecticides, Micronair, spinning disc, spinning cage, acrididae, spray deposition

1 INTRODUCTION

Microencapsulated (ME) pesticide formulations date back to the mid-1970's.[1,2] By enclosing the pesticide active ingredient within a polymer coating, this formulation technique increases chemical persistence, and reduces mammalian toxicity by an average of six- (oral) to 12-fold (dermal). Both of these attributes are advantageous for candidate acridicides. Persistence of two to three weeks, well beyond that achievable with conventional formulations, is required for efficient control of the emerging nymphs of migratory locusts (Orthoptera: Acrididae)[3] and low mammalian toxicity is important in bush habitats where humans, livestock and wildlife are exposed to direct spraying and chemical residues on foliage.

The more specific benefits of microencapsulation over conventional EC or ULV formulations have been summarised as follows,[4,5] although some of these claims are speculative and require verification in the field:

1. Increased residual efficacy because of lower volatility and degradation.
2. Adjustable chemical release rates, enabling dose to be optimised or even reduced.

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3. Reduced evaporation during application and prevention of crystallisation of the active ingredient in adverse application conditions.
4. Safer handling through lower volatility and reduced contact and oral toxicity.
5. Increased selectivity and, possibly, reduced environmental hazard (e.g. reduced fish toxicity, less leaching and reduced drift).
6. Reduced phytotoxicity.
7. Enhanced UV protection of photo-labile products.

In temperate regions ME formulations are applied in water volumes of 100–200 litres ha^{-1}. Ultra low volume (ULV) rates of 1–5 litres ha^{-1} are, however, preferable in locust control, to maximise the area sprayed with a single sprayer tank load and reduce water requirements. However, at ULV rates, undiluted ME formulations may be too viscous to apply efficiently by rotary atomisers, requiring too great an operating pressure within the spray system to achieve the necessary drop-size spectrum.[6] The minimum rate of dilution necessary to permit efficient application should therefore be known. Drop size itself is also important, since this affects the behaviour and distribution of the spray cloud which impinges directly upon insects or foliage in the field.[7–9] Given that ME formulations are aqueous, evaporation is likely to occur and drop size will decrease during and after application, reducing terminal or sedimentation velocity and increasing the time the drops spend in the air.[7] The polymer capsule wall will set the minimum drop size, but the effect on impaction efficiency and tenacity of losing the water coating of the capsule is unknown. In addition, the likely downwind distribution of drops carried on air currents from an operating rotary atomiser system is unknown and swath widths must therefore be determined for the more commonly used sprayer types.

This paper attempts to answer these questions. It reports a series of laboratory- and field-based investigations of the physical performance of a range of ME formulations applied through hand-held, vehicle- and helicopter-mounted rotary atomiser systems. It is the first publication to explore the application characteristics of microencapsulated formulations and these are given in detail. It also reports the results of an initial test of pesticide efficacy in the field in W. Africa.

All the microencapsulated products tested were manufactured and supplied by Pennwalt France SA.

2 METHODS

2.1 Spray systems

In studies of physical performance in the UK (see Section 2.2) a Micronair AU7000 spinning-cage rotary atomiser[10] (Micronair Ltd, Bembridge, Isle of Wight, UK), mounted on a hand-held shaft and powered by a two-stroke engine, was used. The liquid feed to the spray head was provided by an Azo compressed-air-powered sprayer tank which allowed working pressures to be simulated for short periods.

In the field studies, an identical Micronair AU7000 sprayer was used, mounted on a four-wheel-drive vehicle. This version, developed by the Service de Protection des Végétataux (SPV), Mali for locust-control operations, was powered by a two-stroke engine or a 240-V electric motor. A 30-litre stainless steel, pressurised spray tank supplied the liquid to the spray head at pressures up to 3 bar. Although the rotational speed and fan-blade angle were adjustable, the system was run at 9000 rev min^{-1} with a 25° blade angle throughout these tests.

In addition to the spinning cage-rotary atomiser, a Simplex spray system, Model 4900, fitted with four boom-mounted 240-V DC Beecomist Model 360 atomisers was field-tested, mounted on a Bell 206A Jet Ranger helicopter. The atomisers ran at 11 000 rev min^{-1} and were fitted with the largest (D12) restrictor, to control flow rate at 1·126 litres min^{-1} $atomiser^{-1}$ for undiluted ME product and at 5·0 litres min^{-1} $atomiser^{-1}$ when diluted 1 + 1 by volume with water.

Finally, a hand-held Berthoud C8 spinning-disc sprayer was evaluated, with the widest (red) restrictor. This sprayer had a 1·5-litre gravity feed reservoir and was powered by 8 × 1·5-V batteries.

2.2 Physical studies on the AU7000 in the UK

The flow rates achievable with a commercial formulation of diazinon ME and three experimental ME formulations in comparison with an oil-based ULV formulation and water were initially determined. The test substances were diazinon 240 g $litre^{-1}$ ME ('Knox-out' 2 FM) experimental blank ME formulations, with similar viscosity to the diazinon ME, but with differing capsule size spectra (Volume Median Diameters (VMD)[10] 18, 27 and 46 μm), a commercial diazinon 500 g $litre^{-1}$ ULV ('Callisulfan') and water. The spray tank was pressurised to 1·7 or 3·0 bar (170 or 300 kPa) and the Variable Restrictor Unit (VRU) on the atomiser head was adjusted to a range of settings for measurements of flow rate.

To determine whether the spinning cage caused damage to the microcapsules, the sprayer was set horizontally at a height of 1·2 m in a polyethylene tunnel (3 × 10 m) and spray emissions were collected in vertically mounted glass funnels placed at 0·5, 2 and 3 m away from the spray head. Spray deposits were washed with water into a collecting vessel. A 10-ml aliquot of these samples was diluted to 100 ml and a small volume was inspected microscopically for signs of any damage.

Using the microscope facility on an IBAS II (Kontron) image analysis computer[11] the capsule-size spectra of the experimental formulations were compared with those of a diluted sample of each, taken from the spray tank.

The effect of size on capsule aggregation, when applied at ULV, was determined by including various capsule sizes in the test solutions. The effects of viscosity of the ME formulation on drop size were also studied. The size and composition of drops in the spray cloud were therefore determined from the AU7000 rotary atomiser, again spraying from a fixed position at 1·2 m, in a 3 × 10 m polythene tunnel. Three rows of spray collectors, were positioned along the central axis of spraying and 0·8 m either side at 1, 2, 3, 4, 5·5 and 7 m from the sprayer. Aluminium plates (10 cm diam.) were set horizontally at a height of 0·57 m in these positions and a magnesium oxide-coated microscope slide and a 3 × 1 cm strip of glazed, white photographic paper were placed on each plate. The engine throttle on the sprayer was set to maximum and with a blade-angle of 35°, tank pressure of 1·7 bar (170 kPa) and VRU setting of 3, the experimental ME formulations (with added Kenacid red dye at 10 g litre^{-1}) were applied for 5 s (flow rates were 0·4, 0·36 and 0·34 litres min^{-1} for the 18, 27 and 46 μm formulations respectively). Flow rate was restricted to prevent an excessive build-up of spray on the collectors. After the liquid feed from the pressurised spray tank had been turned off, the blades of the atomiser were run for a further 15 s to allow the spray droplets to dissipate fully.

Drops sedimenting upon magnesium oxide-coated microscope slides form a crater 1·5 × their true diameter on impact.[12] The slides collected from the 18- and 46-μm formulations in the present study were analysed using an image analysis technique to estimate VMD and Number Median Diameter (NMD).[11]

Drops landing upon the photographic paper gave a red stain, against which the capsules they contained could be counted, at × 40 magnification. The capsule aggregations were classified into hemispheric, flat (monolayer) and single capsule for each of the experimental formulations.

These measurement techniques were also used to determine the effect of ME dilution rate upon the drop size spectrum and capsule composition of the droplets. Each of the experimental formulations was diluted by 15 and 30% with water.

The initial tests above were carried out <20°C and at >60% relative humidities, to minimise complications of capsule aggregation due to evaporation of the spray solution. To determine if this was a significant problem, tests with the diazinon ME formulation and the standard, oil-based ULV formulation were carried out as described above at 23°C/50% RH and 35°C/20% RH. With a spray head VRU setting of 1, a 10-s application with the ME formulation gave 0·191 litres of product and a 5-s application with the ULV formulation gave 0·21 litres.

2.3 Studies of spray distribution in W. Africa

These studies were undertaken in annual grassland in Mali, W. Africa, during August, 1987. Dilution of the ME formulation was essential with the Berthoud C8 sprayer because the viscosity of the undiluted product was not compatible with the air-bleed system. The flow rates of 0, 20, 33 and 50% (v/v) dilutions were determined by measuring output over 1-min intervals.

The pattern and extent of deposition of the spray swath was determined by allowing spray to drift onto vertically mounted collectors placed on two lines of 2-m bamboo poles, set 2, 4, 6, 8 and 10 m from the sprayer. The poles were placed in fields of annual grasses, characteristic of the favoured habitat for locusts and grasshoppers. Three types of collector were used: MgO-coated slides to determine droplet size, glazed photographic paper strips for visual assessment of droplet number per unit area and 6 × 8·7-cm acetate sheets, wrapped around the poles for volumetric analysis of the spray deposit. The collectors were positioned on the poles at heights of 0·5, 1·0 and 1·5 m; data are only given here for the 0·5-m high collectors because few droplets were collected above this height. MgO-coated slides were also placed at ground level near each pole.

Spraying with the Berthoud C8 took place using diazinon ME, diluted with an equal volume of water to give a flow rate of 0·085 litre min^{-1}. Walking speed was 1·0 m s^{-1} and the mean wind speed during application was 2 m s^{-1} gusting to 4 m s^{-1}. The temperature was 30°C with 56% RH.

After spraying, the MgO slides were photographed for droplet size determination on image analysis computer. The glazed photographic paper strips were examined in the field to determine the number of water-coated or dry capsule impactions per unit area. The acetate collectors were washed in 10 ml water and the solution was analysed in a portable Milton Roy spectrophotometer. The absorbance values were converted to ng cm^{-2} using a calibration formula.

The maximum operating pressure of the vehicle-mounted Micronair AU7000 sprayer was 1·5 bar (150 kPa) A 1 : 1 dilution of most of the test ME formulations was needed in order to permit adequate flow through the system and to prevent blockage of the pressure gauge. A matrix of artificial collectors was again used to evaluate the composition and extent of the spray swath. Two lines of 4-m poles were set 5, 10, 15, 25, 30 and 40 m from the sprayer. Drops of spray, including the Kenacid red dye, were collected on the three collector types, placed at heights of 1, 2 and 3 m with horizontal, ground-based slides at each position:

TABLE 1
Details of Spray Applications and Insecticides Applied During Biological Evaluation Trials in Mali

Insecticide	*Concentration (g AI litre^{-1})*	*Sprayer*	*Applied dose (g AI litre^{-1})*	*Dilution ratio*	*Volume applied (litre ha^{-1})*	*Swath width (m)*	*Speed (km h^{-1})*	*Wind speed (m s^{-1})*	*Temp./Humidity °C/% RH*
Fenitrothion ME	250	C8	150	1 : 1	1·2	4·0	5·4	2	—
Fenitrothion ME	250	C8	250	1 : 2	3·0	4·0	5·4	2–5	—
Chlorpyrifos ME	240	C8	116	1 : 5	2·9	4·0	3·6	0·5–1	—
Fenitrothion ULV	500	AU7000	250	—	0·5	25·0	7·5	1–3	31/47
Fenitrothion ME	250	AU7000	250	1 : 1	2·0	25·0	7·5	2	37/27
Diazinon ME	240	AU7000	500	1 : 1	4·2	25·0	7·5	1–1·5	39/29
Diazinon ME	240	AU7000	650	1 : 1	5·4	25·0	7·5	1–3	39/28
Chlorpyrifos ME	240	AU7000	120	1 : 1	1·0	25·0	7·5	2	38/39
Fenitrothion ME	250	Beecomist	250	—	1·0	26·5	102	1–2	39/31
Diazinon ME	240	Beecomist	240	1 : 1	5·0	23·0	102	1–3	44/23

data for ground and 1 m are given here. Three applications were made in wind speeds varying from 0·5 to 4 m s^{-1}, although a full droplet-size and deposition analysis was undertaken for only one of these. The temperature during each of the sprays was approximately 30°C and the relative humidity varied from 33 to 44%.

2.4 Evaluation of biological efficacy against Sahelian Grasshoppers

These experiments were undertaken near the village of Dilly, 270 km north of Bamako, Mali. The terrain was characteristically Sahelian bush consisting mainly of annual grasses, 20–70 cm tall. Three plot sizes were used, 0·5 ha (70 × 70 m) for the Berthoud C8 sprayer, 4 ha (200 × 200 m) for the Micronair AU7000 sprayer and 10 ha (316 × 316 m) for the Beecomist sprayer.

In the centre of each plot two transects were marked and the number of grasshoppers that flushed (jumping or flying) in front of an observer was recorded. The transects were 2 × 70 m, 1·4 × 200 m and 1·4 × 300 m for the 0·5, 4 and 10 ha plots respectively. Adjacent unsprayed areas were similarly marked and assessed. The counts took place between 08:15 and 12:00 or 16:00 and 18:00 when the temperature was above 27°C and dew had evaporated. Pre-treatment counts were made immediately before each treatment; post-treatment timings were more variable but were generally 2, 4, 24 and 48 h after treatment and up to eight days in some cases. The most abundant species of grasshopper were (in order of abundance) *Oedaleus senegalensis* (Krauss), *Kraussaria angulifera* (Krauss), *Pyrgomorpha conicera* (Olivier), *Cryptocatantops haemorrhoidalis* (Krauss), *Acrotylus blondeli* (Saussure) and *Acorypha glaucopsis* (Walker).

The formulations tested were fenitrothion 500 g litre^{-1} ULV ('Sumithion' 50 ULV; Sumitomo), *via* the AU7000 system, fenitrothion 250 g litre^{-1} ME ('Fenitrocap') *via* all three systems, diazinon 240 g litre^{-1} ME *via* the AU7000 and helicopter systems and chlorpyrifos 240 g litre^{-1} ME ('Pennphos') *via* the hand-held and helicopter systems. Details of applications are given in Table 1. All products were applied at 90° to the prevailing wind, commencing one swath-width in from the downwind edge and working gradually upwind.

The pump pressure and rotational speed of the helicopter spray nozzles cannot be altered and variation in the spray volume is normally achieved by dilution and the use of restrictors. In this case, to avoid too many changes to the calibrated system, swath width was altered by adjusting flying height to achieve the necessary rates.

Weather conditions were monitored during the trial. At 0·1-h intervals, temperature was recorded at heights of 4 m and 0·5 m, relative humidity, wind speed and wind direction were also recorded at the lower height. The weather data were printed out to aid planning and to determine the timings of sprays. Morning treatments were undertaken at 28–34°C, with the wind at 0·5–4·0 m s^{-1} and afternoon treatments at 34–44°C and a wind speed of 0·5–2·0 m s^{-1}.

3 RESULTS

3.1 Physical studies in the UK

Set at 3 bar (300 kPa) and with VRU position 7, the flow rates for water, oil-based ULV and diazinon ME through the AU7000 were 3·00, 2·50 and 1·71 litres min^{-1} respectively. The minimum pressure at which the ME formulation would flow evenly was 1·7 bar (170 kPa). The other ME formulations had similar flow rates to diazinon ME. The mean microcapsule size was lower than the formulation description (10·9 μm for the 18-μm formulation, 16·3 μm for the 27-μm formulation, 22·7 μm for the 46-μm formulation). After spraying, no damage to the ME formulations was seen upon microscopic examination, and the capsule size distributions were unaffected for the 18- and 27-μm formulations. The mean size of the 46-μm formulation, however, decreased from 22·7 to 10·8 μm and the maximum size reduced from 57·3 to 35·3 μm indicating some loss of the larger capsules.

The droplet size statistics for two of the three experimental formulations at each collecting distance are given in Table 2. The 18-μm microcapsule formulation had larger water droplet dimensions, with larger VMD and NMD than the 46-μm microcapsule formulation. This may have been a result of more drops containing hemispherical aggregates of capsules in the 18-μm formulation (Table 3). The proportion of drops containing single-layer aggregates and individual capsules was greatest in the ME formulations with larger initial VMDs, although the effects of this were slightly counteracted by dilution (Table 3). The smallest proportion of mass aggregates (and therefore possibly the most effectively dispersed formulation) was achieved with the 46-μm microcapsule formulation, applied at a dilution rate of 30% (v/v).

The comparison of the diazinon ME and standard ULV sprays in different temperature and humidity conditions revealed that the ME formulation tended to give consistently larger drop sizes (Table 4) than the standard ULV formulation which produced a larger proportion of small droplets (indicated by low NMD values). At the higher temperature and humidity neither formulation reached the collectors at 7 m. At the lower temperature, 8·6% of the ME drops deposited without any carrier liquid. This value increased to 28% at the higher temperature.

TABLE 2
Droplet Size Statistics for the 18-μm and 46-μm Blank ME Formulations Applied using the AU7000 to Artificial Targets at 1–5·5 m from the Sprayer

Formulation VMD (μm)	*Distance from sprayer (m)*	*Mean droplet size (μm)*	*Range of droplet sizes (μm)* Minimum	Maximum	*NMD (μm)*	*VMD (μm)*
18	1	87	26	364	46	122
	2	77	15	250	58	136
	3	89	33	177	70	111
	4	106	54	227	83	126
	5·5	65	14	120	42	90
46	1	0	0	0	0	0
	2	48	11	138	25	98
	3	56	18	108	34	74
	4	71	12	146	52	117
	5·5	76	28	139	53	120

3.2 Spray distribution studies in W. Africa

The mean flow rates of 0, 20 and 33% diluted formulations from the Berthoud C8 sprayer were 0·010, 0·018 and 0·030 litre min^{-1} respectively; however, these flow rates were extremely variable and dependent upon the precise orientation of the spray head. The 50% dilution produced a consistent flow rate of 0·085 litre min^{-1} and at a walking rate of 1 m s^{-1} the potential application rates for 2–10 m swath widths are 1·4–7 litres ha^{-1},

TABLE 3
Composition of the Microcapsules within Droplets after Spraying through an AU7000 at Different Dilution Rates for Three Experimental ME Formulations

Formulation VMD (μm)	*Dilution with water (%)*	*Microcapsule type (%)* Hemispherical	*Monolayer*	*Individual*
18	0	81	4	15
	15	78	16	6
	30	72	16	12
27	0	73	10	17
	15	63	21	16
	30	60	24	16
46	0	53	12	35
	15	33	33	34
	30	29	29	42

TABLE 4
Droplet Size Statistics at 2–7 m down the Spray Swath for Diazinon ME and Oil-Based ULV when Applied using an AU7000 in Different Temperature and Humidity Conditions

Air temperature/RH (°C/%)	*2·0 m* NMD (μm)	VMD	*4·0 m* NMD	VMD	*5·5 m* NMD	VMD	*7·0 m* NMD	VMD
Diazinon ME								
23/50	50	94	50	91	58	83	20	80
35/50	31	93	55	90	5	85	0	0
Oil-based ULV								
23/50	14	73	23	65	15	55	30	68
35/50	12	72	9	58	8	45	0	0

TABLE 5
Droplet Density, Size and Deposition at a Height of 0·5 m up to 20 m Downwind from a Berthoud C8 Sprayer in a Field Test in Mali

Distance downwind (m)	*Droplet number (cm^{-2})*	*Pesticide deposition[a] ($ng\ cm^{-2}$)*	*NMD (μm)*	*VMD (μm)*
2	71·3	1158	30	59
4	39·0	396	36	66
6	7·8	181	27	51
8	9·8	64	35	81
10	2·2	103	21	67
12		30		
14		15		
16		8		
18		4		
20		2		

[a] Deposition values between 12 and 20 m estimated from regression analysis, see text, assuming 600 g diazinon ha^{-1} in 5 litres water.

giving an adequate range for the ME products to be tested.

The droplet density and deposition declined similarly with distance downwind of the C8 sprayer (Table 5). A large proportion of the spray landed within 4–6 m of the sprayer, with droplet density falling below the recommended 25 cm^{-2} close to 4 m. A regression formula described the pattern of swath attenuation:

$$\text{Deposition (ng cm}^{-2}) = \exp\{7{\cdot}4 - 0{\cdot}303 \times [\text{distance from sprayer (m)}]\}$$

$$F_{1,3} = 16{\cdot}57, \quad P < 0{\cdot}05, \quad R^2 = 0{\cdot}85$$

and was used to estimate the deposition pattern to 20 m (Table 5). The drop-size statistics reveal that the largest droplets were impacting within 4 m. Beyond this there was a gentle decline in NMD and VMD values, indicating the combined processes of liquid evaporation from around the capsules and the gradual sedimentation of the larger fractions of microcapsules. The optimal swath width was set at 4 m for this sprayer/formulation combination.

The downwind droplet density pattern for the Micronair sprayer extended over at least 40 m (Table 6). The extrapolation of the deposition data, using an exponen-

TABLE 6
Droplet Density, Size and Deposition at a Height of 0·5 m up to 100 m Downwind from an AU7000 Vehicle-Mounted Sprayer in a Field Test in Mali

			Droplets with water carrier			*Droplets without water carrier*	
Distance downwind (m)	*Droplet number (cm^{-2})*	*Pesticide deposition[a] ($ng\ cm^{-2}$)*	(%)	*NMD* (μm)	*VMD* (μm)	(%)	*NMD* (μm)
5	85·6	1333	100	50	60	0	0
10	68·5	1100	87	56	67	13	24
15	43·4	513	67	55	67	34	27
20	30·4	298	46	44	59	65	27
25	21·6	298	26	47	62	74	26
30	15·4	240	14	0	0	87	16
40	12·6	337	0	0	0	100	25
50		122					
60		77					
70		49					
80		31					
90		19					
100		12					

[a] Deposition values between 50 and 100 m estimated from regression analysis, see text, assuming 600 g diazinon ha^{-1} in 5 litres water.

TABLE 7
Grasshopper Densities Assessed before and after Treatment using a Berthoud C8 Hand-Held Sprayer

Insecticide treatment	*Rate (g AI ha⁻¹)*	*Mean grasshopper number per 100 m² (% reduction)[a]*				
		Pre-treatment	*24 h*	*48 h*	*72 h*	*96 h*
Fenitrothion ME	150	47·9	6·4 (84·3)	1·8 (95·6)	0·8 (97·6)	0·5 (98·8)
Untreated	0		56·8	35·7	69·0	15·4
Fenitrothion ME	250	87·2	1·8 (98·0)	2·0 (97·8)	2·3 (97·4)	
Untreated	0		52·9	82·1	100	
Chlorpyrifos ME	116	63·8	8·1 (87·3)	9·5 (85·1)	8·2 (87·2)	
Untreated	0		20·7	39·0	26·4	

[a] % reduction calculated from pre-spray count.

TABLE 8
Grasshopper Densities Assessed before and after Treatment using an AU7000 Vehicle-Mounted Sprayer

Insecticide treatment	*Rate (g AI ha⁻¹)*	*Mean grasshopper number per 100 m² (% reduction)[a]*							
		Pre-treatment	*8–15 h*	*1 day*	*2 days*	*4 days*	*5 days*	*7 days*	*8 days*
Fenitrothion ULV	250[b]	53	14 (73)	14 (74)	16 (69)	26 (51)			
Fenitrothion ME	250[b]	83	69 (17)	43 (48)	14 (83)	17 (80)		30 (63)	
Diazinon ME	500[c]	69	47 (32)	23 (67)	19 (72)		51 (26)		32 (53)
Diazinon ME	650[c]	28	17 (40)	10 (62)	6 (79)		37 (0)		32 (0)
Chlorpyrifos ME	120[c]	64		23 (65)	16 (76)	54 (16)		38 (41)	

[a] % reduction calculated from pre-spray count.
[b] Trial replicated twice.
[c] Trial replicated once.

TABLE 9
Grasshopper Densities Assessed before and after Treatment using Beecomist Helicopter-Mounted Sprayer

Treatment	*Rate (g AI ha⁻¹)*	*Mean grasshopper number per 100 m² (% reduction)[a]*		
		Pre-treatment	*24 h*	*48 h*
Fenitrothion ME	250	28	7 (74)	3 (90)
Diazinon ME	600	59	10 (83)	3 (96)

[a] % reduction calculated from pre-spray count.

TABLE 10
Grasshopper Densities (100 m²) in Untreated Transects during the Period when the Insecticide Treatments were Applied using an AU7000 Atomiser

Replicate	*Date*								
	29 Sept.	*30 Sept.*	*1 Oct.*	*2 Oct.*	*3 Oct.*	*4 Oct.*	*6 Oct.*	*7 Oct.*	*10 Oct.*
1	92	101	—	68	73	66	106	69	49
2	65	53	—	57	52	68	112	—	108
3	—	—	42·9	29	41	44	53	73	69
Mean % change	0	−5	—	−24	−15	−7	+19	+22	+7

tial regression formula, fitted to the data

$$\text{Deposition of diazinon (ng cm}^{-2}) = \exp\{7{\cdot}1 - 0{\cdot}046 \times (\text{distance from spray (m)})\}$$

$$F_{1,3} = 9{\cdot}97,\ P < 0{\cdot}05,\quad R^2 = 0{\cdot}67$$

suggested that deposits might be measured over at least 100 m, although the optimal swath width was set to 25 m. The percentage of drops with carrier liquid declined along the swath (Table 6), such that by 40 m all the drops were dry when they landed. Coated and dry drop craters could be distinguished on the MgO-coated slides and separate size statistics were obtained for these. The largest drops, possibly containing the largest number of capsules, deposited rapidly, after which there was again a gradual reduction in drop size for those containing water, approaching a minimum VMD of 58 μm. Droplet size for those without water was relatively even along the swath.

3.3 Evaluation of biological efficacy against Sahelian grasshoppers

The mean grasshopper numbers per 100 m^2 and percentage reductions (based on pre-treatment figures) are given in Tables 7, 8 and 9. Grasshopper counts from the untreated transects during the spray period for the AU7000 and helicopter treatments are given in Table 10. No attempt was made to correct the data from the treated plots for fluctuations in density in the untreated transects because of the considerable local heterogeneity, resulting from variations in the rate at which the grass was drying out and becoming unsuitable for grasshopper feeding and oviposition. The control plot populations were not considered to be equivalent to those in the individual treated plots, therefore population trends over time were examined.

The clearest trends relate to the initial effects observed in treated plots over the four days following spray application. In most treatments there was evidence for an initial population decline, followed by recovery. No dying or freshly killed insects were seen after 48 h and prolonged reductions in numbers tended to correlate with reductions in control plots. It was therefore not possible to deduce long-term effects.

The formulations of fenitrothion both proved to be effective, the ME being superior to the standard ULV formulation, although its maximum effects took 24 h longer to occur. Effects were apparent with all three spraying systems.

4 DISCUSSION

Microencapsulated formulations do not seem, at first sight, to be suited to ULV application in tropical conditions. They are basically aqueous and subject to evaporation and they are viscous, requiring dilution of the basic formulation in order to permit application *via* rotary atomisers. They do, however, carry some benefits. They are, for example, unequivocally safer to operators and vertebrate wildlife *via* oral, dermal or inhalation routes. These are potentially major benefits in a part of the world where protective clothing is rarely available and training in correct pesticide storage and handling is limited. In addition, products are often applied to rangeland which supports cattle and other grazing vertebrates that are likely to consume contaminated foliage.

Their potential environmental benefits in terms of reduced side-effects against other organisms, however, remain untested and a priority for future studies. Environmental and operator safety may be improved by manipulating the thickness of the microcapsule wall and further studies are underway to explore these possibilities. Any benefit in terms of improved selectivity or reduced effects on terrestrial or aquatic invertebrates would be of value, given the broad activity-spectrum of many synthetic insecticides.

This study demonstrated the compatibility of this formulation with ULV application in Sahelian conditions. The microcapsules were largely undamaged by atomisation and they could be applied at low volume rates with limited levels of dilution through spinning-disc and spinning-cage atomisers. The smaller microcapsules were found to aggregate within the droplets and thereby may prevent the drift of individual capsules. This may ensure more accurate spray targeting but is undesirable when adopting a drift spraying technique for locust control. Aggregation of microcapsules also increased the droplet size produced compared with a standard ULV formulation and ensured that the average droplet size after spraying remained near to the 60–70 μm range, which is ideal for impaction on vertical vegetation.[12]

The carrier liquid readily evaporated when applied at the higher temperatures but this was less noticeable than for the ULV formulation. Evaporation may limit droplet penetration and thereby swath width under low or windless conditions but as spinning-disc and cage atomisers rely on wind for spray distribution, this should not be a limitation. In this study, spraying in light winds of less than 1 m s^{-1} resulted in a greater variation in insecticide deposition. In the biological trails, an adequate swath width was achieved for the ME formulations in winds of 1–3 m s^{-1} and these were comparable to those used for the ULV applications. The biological efficacy data confirmed that adequate pesticide distribution and control was achieved using the spinning-disc and spinning-cage atomisers. Overall, a higher level of grasshopper control was achieved using the spinning-disc than with the spinning-cage atomisers because a more even insecticide deposition was produced.

The ME products remained active for periods that were at least comparable with ULV formulations with fenitrothion, ME providing the most persistent control. The experimental constraints imposed by the heterogeneous and shifting grasshopper populations prevented a precise evaluation of efficacy or persistence to be carried out. Having established the basic potential of this formulation type for ULV application, laboratory and field studies addressing the basic problems of a relative efficacy and persistence are now required.

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REFERENCES

1. Ivy, E. E. & Pencap, M., An improved methyl parathion formulation. *J. Econ. Entomol.*, **65** (1974) 473–4.
2. Marrs, G. J. & Middleton, M. R., The formulation of pesticides for convenience and safety. *Outlook on Agriculture*, **7** (1973) 231–5.
3. Brader, L., Control of grasshoppers and migratory locusts. In *Proc. Brighton Crop Prot. Conf.* BCPC Publications, Thornton Health, Surrey, 1988 pp. 283–8.
4. Marrs, G. J. & Scher, H. B., Development and uses of microencapsulation. In *Controlled Delivery of Crop Protection Agents*, ed. R. M. Wilkins. Taylor and Francis, London, 1990, pp. 65–90.
5. Tsuji, K., Preparation of microencapsulated insecticides and their release mechanisms. In *Controlled Delivery of Crop Protection Agents*, ed. R. M. Wilkins. Taylor and Francis, London, 1990, pp. 99–112.
6. Quantick, H. R., *Aviation in Crop Protection, Pollution and Insect Control.* Collins, London, 1987, 428 pp.
7. Johnstone, D. R., The influence of physical and meterological factors on the deposition and drift of spray droplets of controlled size. In *Symposium on Controlled Droplet Application.* BCPC Monograph No 22, BCPC Publications, Thornton Heath, Surrey, UK, 1978, pp. 43–57.
8. Spillman, J. J., The efficient aerial application of sprays. In *Rational Pesticide Use*, ed. K. J. Brent & R. K. Atkin. Cambridge University Press, Cambridge, 1987, pp. 107–21.
9. Symmons, P. M., Dobson, H. M. & Sissoko, M., Pesticide droplet size and efficacy: a series of trials on grasshoppers. *Crop Protection*, **10** (1991) 136–44.
10. Matthews, G. A., *Pesticide Application Methods.* Longman, London, 1979, 336 pp.
11. Jepson, P. C., Cuthbertson, P. S., Thacker, J. R. & Bowie, M. H., A computerised droplet size analysis system and the measurement of non-target invertebrate exposure to pesticides. *Asp. Appl. Biol.*, **14** (1987) 97–112.
12. Courshee, R. J., Drift spraying for vegetation baiting. *Bull. Entomol. Res.*, **50** (1959) 355–69.